Yield and Wood Quality of Hybrid Cottonwood Grown in Two-Year Rotation

by

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The results of a study of yield and wood quality of 2-year-old coppices grown on 4-year-old roots of 35 euramerican poplar clones in a replicated, intensively managed, dense plantation are described.

The clonal variation was considerable in every aspect studied. The clonal averages for diameter at 1.37 m height ranged from 1.8 cm to 3.3 cm, and for total height ranged from 3.4 m to 5.2 m. The clonal production rates suggested by these limited samples vary from 26.7 m^3/ha to 161.4 m^3/ha in green volume, 23.1 t/ha to 94.5 t/ha for green biomass and were estimated to be 9.9 t/ha to 38.3 t/ha for oven-dry biomass. The clonal variation in branch green weight (13.2% - 34.6%), bark volume (14% - 24%) and pith volume (1% - 7%) was also considerable but not correlated to the total yield. The clonal values for average weighted specific gravity of bole xylem ranged from 0.234 to 0.341, and of bark from 0.157 to 0.510. The average weighted fibre length in bole xylem ranged from 0.60 mm to 0.87 mm, and in bark from 0.98 mm to 1.34 mm. The clonal variation in cell diameter, cell wall thickness, and in tension wood content was of the order of 30% or more. The wide variation in many of the yield and wood characteristics showed that high selection potential existed among the studied clones.

The fibre-pulping parameters and the tissue composition suggested reasonable papermaking suitability of the analysed wood. The pulp- and paper-making quality of the juvenile coppices was shown to be satisfactory by studies accomplished in several pulping research laboratories.

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INTRODUCTION

The demand for products based on wood fibre is expected to rise sharply with time (Van der Meiden 1971). Silviculturists in many countries are now being confronted with a structural shift in the wood market. A reevaluation of many traditional methods of management will be necessary and new concepts of timber production will have to be developed.

Discussing "The Forestry Picture Today and Forty Years Hence", Drysdale (1969) suggested that in Canada there would be a gradual switch from a single tree harvesting system, in which the size of individual trees is economically important, to a multi-tree system, that depends more on the total volume per acre and which would allow shorter rotation periods. While the merchantable size of trees is limiting in the lumber, veneer and plywood industries, the wood-fibre-based industries have less stringent requirements in their raw material size and shape as long as it is of suitable quality. The considerable flexibility of the wood-fibre-based industries in their raw material requirements may allow the utilization of small sized trees, and open the way to consider new fibre-producing concepts and short rotations.

Many poplar *(Populus spp)* clones grow vigorously, especially when suckering or coppicing, and produce a large volume of wood fibre on many small, densely-grown trees in just a few years. Fast-grown, juvenile, wood, of such material, could become an important source of raw material for pulp and other fibre based industries.

The purpose of our study is to compare the two-year productivity and wood- and fibre-quality of 35 euramerican hybrid poplar clones with respect to their potential suitability for fibre products. Emphasis is directed toward screening the various clones in terms of relative merit, and is not particularly intended to indicate production values attainable from large-scale application.

BACKGROUND

The 10- to 20-year rotations, suggested by Einspahr and Benson (1968) for aspen in Lake States, and the 10-year rotations, designed for pulpwood production of hybrid poplars in Southeastern Ontario (Zsuffa 1973), seem short when compared to the existing rotations for natural stands of poplar. However, they may look long when compared to 1- to 5-year "mini-rotations" recommended by Schreiner (1970). This concept is similar to the one introduced by McAlpine *et al* (1966) for sycamore fibre production in 1- to 3-year rotation and discussed by many since then.

An extensive review of data on short rotatation forestry was published recently by Ribe (1974), in which data on coppice yield of juvenile cottonwood are summarized from Steinbeck (1973) and Smith and Debell (1973). These, and the information published by Zufa and Balatinecz (1971), Debell *et al* (1972) and Heilman *et al* (1972) show that high yields can be obtained in short rotation periods (Table 1).

TABLE 1 Selected published information on the yield of juvenile cottonwood coppice

Species variety & location	Age at harvest (years)	Stems per acre (ha)	Oven dry tons per acre (t/ha) per year	Reference
P. x *euramericana* clones I-214, Jacometti 78B and I-45/51				
S. Ontario	1	14,500 (34,600)	6.5 - 9.4[a] (14.6 - 21.1)	Zufa and Balatinecz 1971
P. trichocarpa Washington	2	3,600 - 44,000 (8,900 - 108,700)	3.3 - 4.7[b] (7.4 - 10.5)	Heilman *et al* 1972
P. trichocarpa Washington	2	2,700 - 44,000 (6,700 - 108,700)	1.0 - 6.5 (2.2 - 14.6)	DeBell *et al* 1972
P. trichocarpa Washington	2	unknown	1.0 - 6.0 (2.2 - 13.5)	Steinbeck 1973
P. trichocarpa B.C. and Washington	2	2,700 - 44,000 (6,700 - 108,700)	3.6 - 5.2 (8.1 - 11.7)	Smith and DeBell 1973
P. trichocarpa Washington	4	2,700 - 44,000 (6,700 - 108,700)	5.7 - 6.3 (12.8 - 14.1)	Schmidt and DeBell 1973

[a]Oven-dry weight estimated by multiplying fresh weight by 0.49.
[b]Oven-dry weight estimated by multiplying fresh weight by 0.46.

The yields depend greatly on site quality, genetic quality, density of stocking and cultural treatments. Rotation length has much effect on the size of the trees and on the characteristics related to size; however, the total yields, given the correct density of stocking, do not vary much with the age at the time of harvest. Many cottonwood-type poplars grow vigorously, especially when coppicing, and capture the site completely in just one year.

The primary product of poplar coppice growth is fibre. According to Keays *et al* (1974) poplar fibre is used in all pulping processes and in all of the major end-use categories. Its long-term potential is high in kraft, semi-chemical and dissolving-grade pulps and extremely high in mechanical pulps.

It is essential that the juvenile poplar fibres be suitable for the production of paper and paperboard products. Studies have demonstrated that juvenile poplar has such qualities and that many of the former reservations concerning the use of juvenile trees were unfounded (Jayme *et al* 1943, Jayme and Reh 1944, Bersano 1960, Cech *et al* 1960, Masirevic and Oblak 1966, Marton *et al* 1968, Heilman *et al* 1972, Bella and Hunt 1973, Hunt and Keays 1973). According to Ribe (1974), several pulping characteristics may favour the use of juvenile wood. Among these are: the need for smaller amounts of cooking liquor, lower temperature and pressure conditions, and shorter cooking time. The drawbacks could be: lower specific gravity of juvenile wood, lower quality and smaller relative quantities of fibrous material, higher proportion of bark and lower packing properties. All these can result in lower yields and in the need for larger volumes of material to produce an equivalent amount of paper.

The usefulness of juvenile hybrid cottonwood coppices has also been demonstrated in our previous studies. The high yielding one-year-old coppices of *P.* x *euramericana* clones reported by Zufa and Balatinecz (1971) were analysed for fibre and pulping properties. Fibreboards were made from the mechanical pulp produced from the entire leafless coppices. These compared favourably to commercially made Canadian fibreboard in strength and other physical properties. The Institute of Paper Chemistry, Appleton, Wisconsin, USA, analysed samples of one-year-old coppices of *P.* x *euramericana* clones I-45/51 and Jacometti 78B supplied by us and made kraft pulp from the same. Although the specific gravity and the fibre length of the two clones varied significantly, the yields (42% and 43%) and the characteristics of the pulps made of debarked wood were similar[1]. The Pulp and Paper Research Institute of Canada, Montreal, Quebec, made kraft pulp from one-year-old coppices of *P.* x *euramericana* clones I-45/51, I-214 and Jacometti 78B supplied by us. They concluded[2] that, when cooked under appropriate conditions, the debarked coppices can give a pulp that is nearly comparable to a "Standard" hardwood pulp, except that the yield is lower (43% vs. 47% for the "Standard"). When the bark is not removed the yields are 8% to 10% lower, there is slower delignification and lower

[1]Einspahr, D. W. The Institute of Paper Chemistry, Appleton, Wisconsin 54911, USA. Letter of 29 February 1972 on file.

[2]Bolker, H. J. and A. Sakai. Pulp and Paper Research Institute of Canada, 570 St. John's Boulevard, Pointe Claire, P.Q. Canada. Report on "Pulping Characteristics of Cottonwood Coppices", July 1972, on file.

strength (except tear factor), and dark specks suggest difficult bleaching. Although the properties of pulps made from the three clones varied, the yields were similar. The experimental work by these institutions was limited by the small quantities of samples.

Larger amounts of samples of 2-year-old coppices of *P.* x *euramericana* clones DN10, DN20, DN21, DN25, DN28 and I-45/51 described in the present study (see Table 3) and of 1-year-old coppices of clone I-45/51 were sent for a pulping study to Domtar Ltd. Research Centre, Senneville, Quebec[3]. A kraft liquid phase cooking procedure, used to pulp chips from mature trees, was applied on unbarked chips. For purposes of comparison a composite sample of unbarked chips from mature mixed hardwood trees was included. The yields from one-year-old samples were about 10% lower, and the yields from two-year-old samples approximately 4% lower than from regular chips (47.4%). The pulp properties were satisfactory, in general. The bleaching and the physical properties of the bleached pulp made from young coppices were comparable to the mixed hardwood pulp. The clones studied had similar pulp properties and yields.

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[3]Bryce, J. and J. Temler. Domtar Ltd. Research Centre, Senneville P.Q. H9X 3L7, Canada. Report on "Evaluation of One- and Two-Year-Old Hybrid Poplar", November 1974, on file.

Figure 1 *View of hybrid cottonwood clonal test at Kemptville Nursery, just prior to harvesting in late fall 1972.*

MATERIALS AND METHODS

THE PLANTATION

The poplar plantation in this study (Fig. 1) was located at Kemptville nursery, Ontario (45°N, 75°35'W). It was established in the spring of 1969 on a well prepared site. The surface soil is a loamy sand, and the sub-soil is sand (Table 2). It had the quality of a "marginal farmland". Unrooted, 8-inch-long (20 cm) cuttings of 35 euramerican poplar clones were planted (Table 3). The spacing was 1 x 3 ft (0.30 x 0.91 m). Five-tree plots of each clone were established in four randomized replications.

TABLE 2 Soil characterization of the poplar field at Kemptville Nursery

Soil property	Top-soil	Sub-soil
Physical		
Texture classification	loamy sand	sand
Sand %	85	91-94
Silt %	10-11	2-5
Clay %	5	4
Organic matter %	1-2	0.5-0.7
Chemical		
Inorganic materials mg/g		
Phosphorus	0.021-0.038	0.016-0.028
Calcium	0.076-0.084	0.050-0.098
Magnesium	0.006-0.008	0.002-0.005
Potassium	0.011-0.052	0.005-0.052
Manganese	0.000-0.003	0.000-0.003
C/N	10-13	6-17
pH (H_2O)	5.2-6.2	5.6-5.8

The management was intensive; the plantation was kept free of weeds and irrigated when needed. Each year, at the beginning of June, the plantation was fertilized. In 1969, 100 lb/acre (112 kg/ha) and in 1970, 200 lb/acre (224 kg/ha) of 10-10-10 NPK fertilizer were applied. In 1971, 100 lb/acre (112 kg/ha) of 19-19-19 NPK fertilizer and 50 lb/acre (56 kg/ha) of ammonium nitrate were used. Finally, in 1972, 100 lb/acre (112 kg/ha) of 19-19-19 NPK were applied. The irrigation and fertilization were done routinely on the whole nursery compartment, to which the poplar plantation belonged. The necessity of these treatments in poplar plantation and the significance of the same on the poplar growth was not established.

The coppices were cut to the root collar and used for cuttings in the spring of 1970 and 1971. In the spring of 1972 the coppices were thinned to one stem per root system and left to grow for another year.

TABLE 3 List of studied euramerican poplar clones (*P.* x *euramericana* (Dode) Guinier = *P. deltoides* x *P. nigra*)

Clonal no.	Clone	Initial stock obtained
DN1	Allenstein	Germany
DN2	Baden 431	Germany
DN3	Dolomiten	Germany
DN4	Flachslanden	Germany
DN5	Gelrica	Germany
DN6	Grandis	Germany
DN7	Heidemij	Germany
DN9	Lons	Germany
DN10	Robusta	Germany
DN11	Steckby	Germany
DN12	Vert de Garonne	France
DN13	Dromling	Germany
DN14	Harff	Germany
DN15	Regenere d'Aube	France
DN16	Regenere Batard d'Hauterive	France
DN17	Robusta	France
DN18	Tardif de Champagne	France
DN19	Blanc de Poitou	France
DN20	I-61/59	Italy
DN21	Jacometti 78B	Germany via Yugoslavia
DN22	I-262	Italy via Yugoslavia
DN23	I-106/56	Italy via Yugoslavia
DN24	I-132/56	Italy via Yugoslavia
DN25	I-55/56	Italy via Yugoslavia
DN26	B-56	Italy via Yugoslavia
DN28	Ostia	Germany via Yugoslavia
DN29	Chopa de Santa Fe	Spain via Yugoslavia
DN30	Canada Blanc	Italy via Yugoslavia
DN31	Negrito de Granada	Spain via Yugoslavia
DN32	Virginie de Frignicourt	France
DN33	Virginie de Nancy	France
D41	I-63/51	Italy
I-214	I-214	Italy via United Kingdom
I-455	I-455	Italy via United Kingdom
I-45/51	I-45/51	Italy via United Kingdom

SAMPLING

All surviving trees were numbered and cut flush with the top of the parent stool in November 1972 (Fig. 2). For each tree, fresh weights (to the nearest 10 g) were determined immediately for the bole and branches separately. The following measurements were also made: heights to the end of the first- and second-year nodal increments (to the nearest 5 cm); total length of a representative major branch (to the nearest centimetre); and bole diameter at 1.37 m height (to the nearest 0.5 cm).

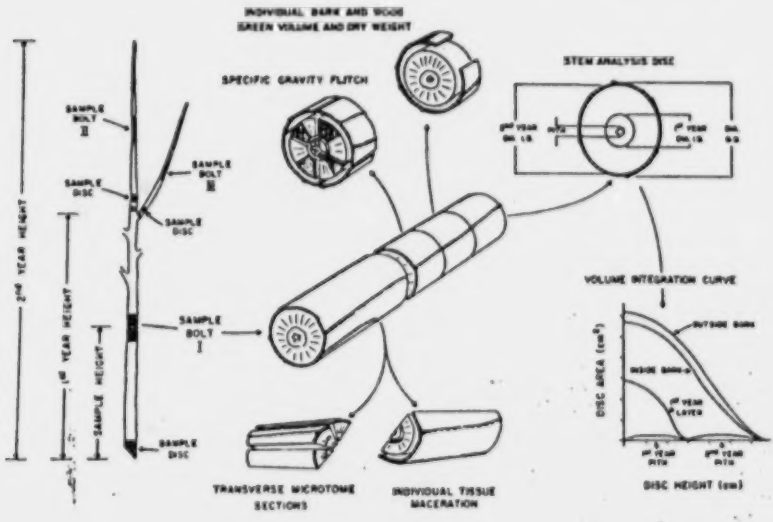

Figure 2 Sampling scheme used in evaluating productivity and quality of hybrid cottonwood clones, showing matching procedures used in dividing materials for different purposes.

From each clonal plot in every replication an average-sized tree was chosen for tissue analysis and density and volume determination. Discs (2 cm thick) were taken from the base of the tree, the base of the second year internode and the base of the sample branch of each representative specimen. Bolts 10 to 15 cm long were taken from the mid point of the first- and second-year internodes and of the representative branch. Both discs and bolts were placed in tightly wrapped polyethylene bags and stored in a freezer until used for analysis. Fibre analysis, density and volume calculations were done on these samples. Each bolt was cut in half, the portions being used for either fibre and tissue analysis or density and volume determination respectively (Fig. 2).

Fibre Analysis

Partial bolts selected for fibre analysis were split longitudinally, the respective portions being used for either fibre length determination or cell thickness and tissue composition, effectively side-matching these sources of data. Each of the xylem annual layers and the bark layer was pulped separately. Permanent mounts of macerated tissue, delignified in warm peracetic acid, and stained in Victoria Blue B (1% in 50% ethyl alcohol), were prepared. Fibre lengths were measured to the nearest millimetre on projection images at a scale of 20 cm = 1 mm. Only undamaged cells were measured, chosen arbitrarily by scanning the slides systematically until a total of 50 individual cells were measured. Preliminary tests showed that

estimates of mean fibre length could be obtained efficiently by this sample size. Average fibre length of the bole was computed by weighting tissue values proportional to tissue volume contribution.

The other longitudinal half of each sample bolt portion was used for microtome sectioning. Transverse sections 15 µm thick, including bark, were taken and stained by the safranin - fast green method and viewed at 1000 X magnification with Nomarski Interference Contrast. Tangential fibre cell widths and lumen diameters were measured to the nearest 0.5 µm using an eye-piece micrometer. Radial cell wall thickness was computed as half the difference between cell and lumen diameter. Presence or absence of gelatinous cell wall layers, indicating a tension wood condition, was noted for each cell measured. Percentage occurrence of tension wood and wall thickness adjusted to eliminate tension wood layers were computed. Because of the random arrangement of fibres in poplar, cells were chosen systematically in a radial direction but in a somewhat diagonal fashion such that 5 uniformly spaced cells were chosen per run from earlywood to latewood until a total of 40 were accummulated. This sampling intensity gave an efficient estimate of mean cell thickness parameters.

Tissue Analysis

Tissue composition was determined on six arbitrarily chosen clones (DN10, DN20, DN21, DN25, DN28, I-45/51) using an integrating eye-piece with 100-point grid at 320 X magnification with Nomarski Interference Contrast. Seven fields arranged radially within the growth layer of each sample were analysed according to the percentage "hits" on lumen (void) or cell wall of each of the cell types (fibre, vessel, or parenchyma). In the bark tissue, sampling was restricted to recording the proportion of hits on fibre wall only, because of the complexity of cell types.

Specific Gravity

Specific gravity was determined on the remaining parts of each bolt sample, end-matching the sources of fibre data. Four wood blocks (each 1 cm^3) with bark and pith removed were prepared from the sample bolts. In addition, one sample per bolt with bark and pith intact was prepared. The two annual growth layers were separated when present. The samples were individually aspirated in water under alternating vacuum for 10 days until saturated. A small amount of detergent was added to the water for the saturation of single samples with bark and pith, to prevent microbiological disintegration of bark tissue during aspiration which required 14 days. The saturated weights were determined to the nearest 0.1 mg, the samples were oven-dried for 24 h at 105°C, and then reweighed. Specific gravity based on green volume and oven-dry weight was calculated according to the maximum moisture content method of Smith (1954). Average bole specific gravity was determined by a volume weighting procedure similar to that used for average fibre length. In addition, direct estimate of bark specific gravity was made by separating bark tissue from discs end-matched to the wood blocks used for wood density. Green volume was measured by displacement of water in a Russel volumeter and the sample was then oven-dried.

Volume Determination

Volume determinations were made using discs cut from the fresh sample bolts and from those obtained from the base of the respective internodes. On each

disc, diameter measurements (to the nearest 0.025 mm) were made for bark, annual rings and pith. Two mean diameters were always measured using a traversing calibrated vernier stage and 12 power binocular stereomicroscope fitted with an ocular cross-hair reticule. Respective diameter measurements were converted to area and plotted over the appropriate sample height to give stem analysis profiles. Mechanical integration of these tree curves produced volume (cm^3) data by tissue component (bark, pith, first year and second year volume).

Yield

Per acre estimates of green volume yield were obtained from weight/volume relationships for entire bole portions and sample discs of branch material. These factors were applied to the total respective bole and branch weights for the 20 trees of a clone in 4 replicates occupying 60 ft^2 (5.57 m^2) and multiplied by 726 to convert to an acre-basis (0.405 ha). While the clonal planting order was randomized to reduce clonal interaction effects, the lack of individual surrounds for the clones, combined with the limited sample size would suggest that the per-acre yield conversions should be considered as nominal values or first-order approximations and not necessarily reflective of what could be obtained from an actual acre of pure clone.

Estimates of oven-dry yield per acre were derived from green yield in a fashion similar to that for volume. Ratios for each clone of dry weight over green weight were developed for sample discs, weighted proportional to volume contribution of tissue from each sampling position. The ratios were applied to the green weight data per acre for bole and branches separately.

RESULTS AND DISCUSSION

SURVIVAL AND GROWTH (Table 4)

Five of the thirty-five clones planted in the test failed to survive and/or grow satisfactorily. These clones (DN4, DN12, DN29, DN31, D41) were therefore eliminated from the sampling and are not included in the results.

Survival was good for the remainder of the clones. Half of them had 90% or more survival. Clones DN3 and DN9 had no mortality. The lowest survival (75%) was with clones DN21 and I-45/51.

The clonal variation in growth was considerable. Average diameter ranged from a minimum of 1.8 cm (0.7 inches) for clones DN15, DN26, and I-455, to a maximum of 3.3 cm (1.3 inches) for clones DN20 and DN25. In a similar fashion, there was a wide spread of average total height, from 3.4 m (11.2 ft) for clone I-455 up to 5.2 m (16.9 ft) for clone DN25. Thus DN25 and I-455 had the best and worst respective growth in both parameters in the test.

TABLE 4 Survival and growth after two years

Clone	Survival %	Diameter at breast height (1.37 m) cm	inches	Height m	ft
DN1	85	3.0	1.2	4.9	16.0
DN2	85	2.8	1.1	4.6	15.2
DN3	100*	2.3	0.9	4.0	13.0
DN5	90	2.0	0.8	3.7	12.1
DN6	85	2.5	1.0	4.0	13.0
DN7	85	2.3	0.9	4.3	14.0
DN9	100*	2.0	0.8	3.9	12.9
DN10	90	2.8	1.1	4.5	14.8
DN11	80	2.0	0.8	3.7	12.0
DN13	85	2.3	0.9	3.8	12.6
DN14	95	2.0	0.8	4.0	13.1
DN15	85	1.8-	0.7	3.6	11.8
DN16	90	2.0	0.8	3.7	12.2
DN17	95	2.5	1.0	4.3	14.1
DN18	95	2.0	0.8	3.8	12.5
DN19	85	2.0	0.8	4.1	13.6
DN20	95	3.3*	1.3	4.8	15.6
DN21	75-	2.8	1.1	4.5	14.6
DN22	80	2.5	1.0	4.8	15.6
DN23	90	2.5	1.0	4.5	14.7
DN24	95	2.5	1.0	4.3	14.2
DN25	95	3.3*	1.3	5.2*	16.9
DN26	85	1.8-	0.7	3.6	11.8
DN28	95	2.5	1.0	4.6	15.0
DN30	95	2.8	1.1	4.6	15.0
DN32	95	2.0	0.8	3.6	11.9
DN33	85	2.8	1.1	4.4	14.5
I-45/51	75-	3.0	1.2	4.3	14.0
I-214	85	2.5	1.0	4.2	13.9
I-455	80	1.8-	0.7	3.4-	11.2

Note: In this table and others, the symbols * and - indicate maximum and minimum values respectively.

YIELD

Green Biomass (Table 5)

The maximum yield was approximately 94.5 t/ha (42.1 tons/acre) for clone DN25 and the minimum was 23.1 t/ha (10.2 tons/acre) for clone DN5, about a four-fold difference in magnitude. The contribution of branches was not in relation to the total yield. For example, DN5 which had the lowest yield also had the lowest percentage weight in branches (13.2%) while DN25, the best producer, had only a moderate branch value of 23.1%, the maximum being for clone DN15 (34.6%).

TABLE 5 Green biomass after two years

Clone	Surviving green tree weight (kg)				Total green yield	
	Bole wood	Branch wood	Total tree	% Branch	kg/ha	lb/acre
DN1	34.59	10.02	44.61	22.5	79 996	71 251
DN2	31.57	9.14	40.71	22.4	73 001	65 022
DN3	9.37	2.02	11.39	17.7	40 850	36 384
DN5	5.59	0.85	6.44	13.2-	23 097-	20 572
DN6	8.96	1.92	10.88	17.6	39 020	34 755
DN7	9.75	2.60	12.35	21.0	44 293	39 451
DN9	8.99	1.52	10.51	14.5	37 693	33 573
DN10	28.09	5.59	33.68	16.6	60 396	53 794
DN11	6.83	1.20	8.03	14.9	28 799	25 651
DN13	8.51	2.34	10.85	21.6	38 913	34 659
DN14	7.18	2.08	9.26	22.5	33 210	29 580
DN15	5.29	2.80	8.09	34.6*	29 014	25 843
DN16	10.40	2.97	13.37	22.2	47 951	42 709
DN17	15.82	5.36	21.18	25.3	75 961	67 657
DN18	5.23	1.25	6.48	19.3	46 480	41 399
DN19	11.46	3.31	14.77	22.4	52 972	47 181
DN20	40.33	10.80	51.13	21.1	91 687	81 665
DN21	21.68	4.25	25.93	16.4	46 498	41 415
DN22	19.32	3.94	23.26	16.9	41 710	37 151
DN23	23.38	5.49	28.87	19.0	51 770	46 111
DN24	9.90	3.14	13.04	24.1	46 767	41 655
DN25	40.57	12.17	52.74	23.1	94 574*	84 236
DN26	6.33	1.02	7.35	13.9	26 360	23 479
DN28	21.67	5.62	27.29	20.6	48 937	43 588
DN30	22.73	7.58	30.31	25.0	54 352	48 411
DN32	8.62	3.22	11.84	27.2	42 463	37 822
DN33	18.87	6.87	25.74	26.7	92 315	82 224
I-45/51	24.71	5.52	30.23	18.3	54 209	48 283
I-214	19.96	5.21	25.17	20.7	60 180	53 602
I-455	7.50	1.75	9.25	18.9	33 175	29 548

Green Volume Bole Components (Table 6)

Considerable variation was exhibited in the relative first-year growth, ranging from 9.0% of the total bole volume for DN2 to 33.2% for DN14. This variability is of significance due to the higher specific gravity and shorter fibre length of the first annual ring, as will be shown later.

Bark comprised 24% of the bole volume in DN17 and DN14 but only 14% in I-214. Bark values were not well-correlated with bole volume. Even pith volume showed diversity, clones DN2 and DN18 having only 1% of the bole volume in pith and clone DN25 having the maximum contribution of 7% pith. The pith volume did not correspond to gross volume.

In terms of green volume yield of bole material per unit area, there was a very large degree of variation, from a minimum of 26.7 m^3/ha (381.4 ft^3/acre) to a maximum of 161.4 m^3/ha (2306.0 ft^3/acre), a difference of almost 135 m^3/ha (20 cunits/acre).

TABLE 6 Green volume components

Clone	% of gross bole volume			Estimated yield	
	Bark	First year's growth	Pith	(m^3/ha)	(ft^3/ac)
DN1	18	17.6	3	115.9	1656.3
DN2	17	9.0-	1-	106.3	1518.5
DN3	15	17.2	3	52.9	755.7
DN5	22	18.0	3	26.7-	381.4-
DN6	18	17.1	3	52.1	745.1
DN7	21	25.2	5	45.7	653.3
DN9	20	25.6	3	42.5	607.4
DN10	18	17.2	3	75.4	1077.1
DN11	20	16.6	2	38.5	550.9
DN13	21	18.0	3	51.4	734.5
DN14	24*	33.2*	4	40.8	582.7
DN15	20	29.3	3	63.0	900.5
DN16	17	17.5	2	55.4	791.0
DN17	24*	11.8	2	105.5	1507.9
DN18	17	15.5	1-	57.8	826.4
DN19	19	24.4	4	65.2	932.3
DN20	17	18.6	3	161.4*	2306.0*
DN21	19	9.6	2	61.3	875.8
DN22	17	25.5	6	46.0	656.9
DN23	16	21.1	2	59.8	854.6
DN24	17	13.0	2	67.2	960.6
DN25	18	28.0	7*	112.2	1603.3
DN26	16	18.5	2	34.1	487.3
DN28	18	14.7	2	66.0	942.9
DN30	18	16.0	2	86.2	1232.5
DN32	18	24.6	2	71.7	1024.1
DN33	18	20.8	2	132.4	1892.9
I-45/51	20	19.0	4	79.6	1137.1
I-214	14-	17.9	5	82.0	1172.4
I-455	19	31.2	4	43.5	621.5

Oven-dry Biomass (Table 7)

As would be expected, a wide variation exists, values ranging from a low of 9869 kg/ha (8805 lb/acre) for DN15 to a high of 38 294 kg/ha (34,165 lb/acre) for DN25. This difference is almost 30 t/ha (12.5 tons/acre). The branch contribution to oven-dry biomass was slightly higher on average than to green yield, presumably due to the higher specific gravity of branches. No uniform factor for converting green to dry yield could be applied, because of clonal differences in basic density and perhaps moisture content (the latter factor was not explored).

TABLE 7 Estimated oven-dry biomass after two years

Clone	Total yield kg/ha	Total yield lb/acre	Branches %
DN1	31 800	28 371	25.2
DN2	32 200	28 728	26.5
DN3	14 997	13 380	18.3
DN5	10 327	9 213	16.0-
DN6	15 553	12 876	19.6
DN7	17 203	15 349	25.6
DN9	16 242	14 491	16.8
DN10	24 975	22 282	18.2
DN11	11 088	9 892	19.2
DN13	16 437	14 665	23.0
DN14	15 046	13 424	24.7
DN15	9 869-	8 805-	37.2*
DN16	18 353	16 374	28.4
DN17	32 539	29 030	28.2
DN18	18 340	16 363	21.2
DN19	21 278	18 984	27.2
DN20	37 041	33 047	25.2
DN21	19 049	16 995	20.9
DN22	16 687	14 888	22.2
DN23	21 676	19 339	22.8
DN24	20 156	17 983	27.6
DN25	38 294*	34 165*	26.6
DN26	10 670	9 520	17.3
DN28	21 557	19 233	25.6
DN30	24 318	21 696	27.0
DN32	15 990	14 266	29.0
DN33	36 324	32 408	29.0
I-45/51	22 025	19 650	22.3
I-214	23 129	20 635	23.7
I-455	11 063	9 870	18.1

WOOD QUALITY

Specific Gravity (Table 8)

Data for bole xylem was weighted proportional to the volume contribution of respective annual layers of each nodal increment, since relative density tended to vary with position and tissue age. Variation in relative density was appreciable and tended to be lower than for mature poplar, the maximum being 0.341 for DN17, almost normal for mature cottonwood tissue (Besley 1959), and the minimum 0.234 for DN22, well below "normal average".

Similar to the general findings of Fegel (1941), the specific gravity of branchwood tended to be higher, but less variable, than of corresponding bole wood.

Bark values showed extreme variation, ranging from 0.157 for DN22 (which also had the lowest bole density), to 0.510 for DN14. The variation in bark density may be a reflection of low intensity sampling, but is not surprising in view of the heterogeneity of bark tissue relative to xylem.

For the second nodal increment and branches, wood alone was about 10% denser than wood with bark and pith intact. This relationship is consistent in direction, but variable in magnitude, probably reflecting variations in both bark density and relative contributions of bark and pith volume.

Pulp yield per cooking cycle tends to be a direct function of specific gravity because high bulk density means that more dry matter is contained in the volume of chips that can be packed into a digester. Density may thus prove to be of great significance to the relative economics of small-wood pulping.

TABLE 8 Average specific gravity (green volume, oven-dry weight)

Clone	Bole xylem (weighted by volume)	Branch	Bark
DN1	0.290	0.312	0.415
DN2	0.303	0.313	0.490
DN3	0.248	0.270	0.288
DN5	0.296	0.312	0.307
DN6	0.283	0.282	0.258
DN7	0.284	0.278	0.310
DN9	0.306	0.313	0.418
DN10	0.306	0.306	0.344
DN11	0.262	0.239	0.301
DN13	0.303	0.281	0.293
DN14	0.288	0.317	0.510*
DN15	0.277	0.262	0.284
DN16	0.271	0.272	0.288
DN17	0.341*	0.217	0.434
DN18	0.298	0.290	0.256
DN19	0.265	0.302	0.240
DN20	0.270	0.311	0.441
DN21	0.290	0.295	0.325
DN22	0.234-	0.255	0.157-
DN23	0.292	0.319	0.434
DN24	0.313	0.302	0.392
DN25	0.257	0.275	0.294
DN26	0.234	0.253	0.315
DN28	0.309	0.324*	0.334
DN30	0.280	0.278	0.299
DN32	0.250	0.283	0.256
DN33	0.288	0.272	0.320
I-45/51	0.286	0.280	0.287
I-214	0.238	0.262	0.245
I-455	0.285	0.250-	0.241

Fibre Length (Table 9)

Average bole fibre length has been derived by weighting proportional to volume. Maximum bole fibre length occurred in clone I-45/51 (0.87 mm), and the minimum in DN17 (0.60 mm). Branch material had shorter fibre lengths, as noted also by Fegel (1941) and Besley (1959), whereas bark tissue (Fig. 3) had considerably longer fibres, approaching the normal average of mature cottonwood tissue (Besley 1959). The maximum average bark fibre length was 1.34 mm (clone I-45/51) and the minimum 0.98 mm (clone I-455). It is notable that maximum and minimum bark and branch values (clones I-45/51 and DN19 respectively) correspond in rank with their appropriate bole values.

Fibre length is important to paper quality. Long fibres impart high tear, burst, tensile and fold resistance properties to the pulp and resultant papers (Anon. 1960).

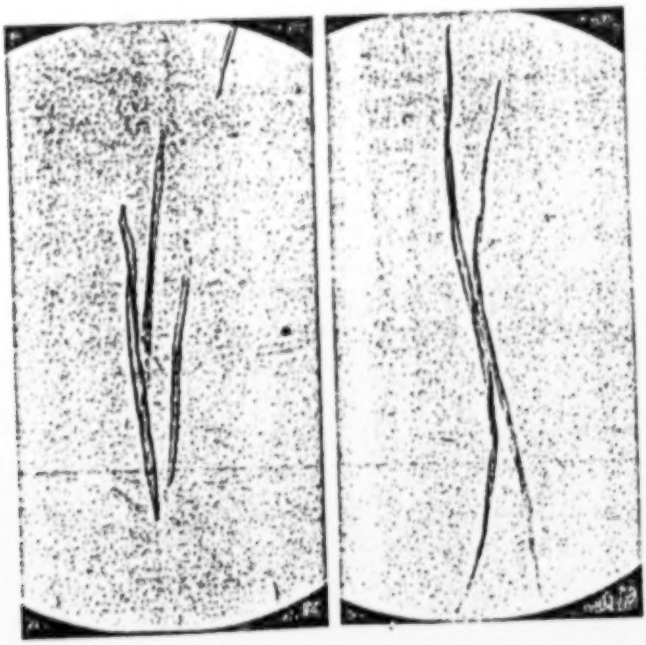

Figure 3 *Fibres separated by maceration from tissues of clone I-45/51. Left: longest second year xylem fibre shown is 0.80 mm long (clonal tissue average 0.94 mm). Right: longest bark fibre is 1.47 mm long (clonal tissue average 1.55 mm).*

TABLE 9 Average fibre length in millimetres

Clone	Bole xylem (weighted by volume)	Branch	Bark
DN1	0.72	0.63	1.16
DN2	0.76	0.63	1.21
DN3	0.67	0.61	1.14
DN5	0.71	0.55	1.18
DN6	0.70	0.59	1.15
DN7	0.69	0.54	1.10
DN9	0.68	0.51	1.10
DN10	0.76	0.66	1.24
DN11	0.61	0.59	1.23
DN13	0.70	0.54	1.08
DN14	0.63	0.49	1.15
DN15	0.68	0.55	1.14
DN16	0.71	0.58	1.20
DN17	0.60-	0.58	1.23
DN18	0.72	0.57	1.20
DN19	0.60-	0.49	1.09
DN20	0.83	0.71*	1.33
DN21	0.70	0.61	1.33
DN22	0.65	0.57	1.14
DN23	0.65	0.48-	1.07
DN24	0.69	0.56	1.20
DN25	0.77	0.58	1.26
DN26	0.71	0.58	1.30
DN28	0.78	0.58	1.17
DN30	0.69	0.59	1.13
DN32	0.70	0.55	1.15
DN33	0.72	0.55	1.18
I-45/51	0.87*	0.70	1.34*
I-214	0.66	0.51	1.20
I-455	0.61	0.52	0.98-

Fibre Thickness (Table 10)

Cell dimensions are correlated with wood density. In addition they affect pulp and paper strength. Thick cell walls tend to produce paper of high tear resistance but low burst and tensile strength and fold resistance (Anon. 1960).

Cell and lumen diameters of the xylem showed variation of 30% between clones. Clone I-45/51 showed maximum values in cell and lumen diameters (19.2 µm and 15.9 µm respectively, about normal for cottonwood (Marton and Agarwal 1965), and DN24 was close to minimum.

In Table 10 wall thickness values are given both as gross averages and as averages of cells not containing ("adjusted for") tension wood. The maximum wall thickness observed (1.67 µm for DN17) was less than the normal for cottonwood (2.1 µm, Marton and Agarwal 1965). There was no good correlation between cell diameter and cell wall thickness of a clone. The maximum and minimum "adjusted" and "unadjusted" clonal values for wall thickness do not correspond mostly because of the variation in incidence of tension wood rather than the particular differences in "G" layer thickness.

The clonal variation in tension wood content was considerable (from 0 to 45%).

TABLE 10 Average fibre thickness of xylem

Clone	Tangential diameter (µm)	Wall thickness (um) (unadjusted)[a]	(adjusted)[b]	Tension wood %	Lumen diameter (µm)
DN1	16.76	1.72	1.57	24.38	13.31
DN2	17.07	1.99*	1.60	45.00*	13.09
DN3	17.16	1.46	1.46	0	14.24
DN5	16.69	1.77	1.55	39.38	13.15
DN6	16.98	1.70	1.56	18.75	13.59
DN7	15.78	1.59	1.53	7.50	12.50
DN9	15.75	1.64	1.50	28.75	12.46
DN10	17.57	1.73	1.57	17.50	14.10
DN11	15.87	1.66	1.62	9.38	12.56
DN13	15.50	1.57	1.57	5.00	12.35
DN14	15.61	1.48	1.47	1.25	12.54
DN15	16.86	1.40	1.40	0	14.06
DN16	18.17	1.48	1.48	0	15.20
DN17	15.58	1.77	1.67*	15.00	12.04
DN18	15.17	1.41	1.41	0	12.35
DN19	16.69	1.68	1.64	5.62	13.34
DN20	18.05	1.59	1.59	0	14.88
DN21	16.86	1.64	1.52	12.50	13.59
DN22	17.90	1.41	1.38-	3.12	15.09
DN23	15.08	1.89	1.60	44.38	11.29-
DN24	14.92-	1.39-	1.39	0	12.15
DN25	17.85	1.58	1.56	3.75	14.69
DN26	17.54	1.49	1.49	0	14.55
DN28	17.16	1.52	1.49	5.62	14.12
DN30	16.13	1.67	1.53	13.12	12.78
DN32	16.64	1.47	1.46	1.25	13.71
DN33	17.41	1.41	1.41	0	14.58
I-45/51	19.22*	1.68*	1.57	13.12	15.86*
I-214	18.28	1.48	1.48	0	15.33
I-455	18.15	1.47	1.44	1.25	15.21

[a]Mean includes all cells sampled (including tension wood cells with "G" layer).
[b]Mean includes only normal cells (excluding tension wood cells with "G" layer).

Fibre Pulping Parameters (Table 11)

Data on fibre characteristics may be more usefully considered in the form of combined values or coefficients which have functional relationship to pulp and paper strength. The coefficients shown in Table 11 express bonding power of the cells which develop strength in pulp and paper sheets by means of surface-area contact. Collapsable, long cells produce the best sheets (Thomas[4], Horn 1972).

The flexibility coefficient (lumen diameter/cell diameter), which is positively related to breaking length, showed relatively little clonal variation (13%), and tended to be higher than for many tree species. The felting index (cell length/cell diameter), and L/T ratio (cell length/cell wall thickness), which are directly correlated to burst and tensile strength, showed more clonal variation (43% and 56% respectively). Similarly the clonal variation in Runkel ratio (double cell wall thickness/lumen diameter) was 52%. The last three ratios were of lower values than for most other species. The Runkel ratio is considered to indicate papermaking suitability when values are less than unity. Clearly, all clones are well within this threshold value.

[4]Thomas, G. H. S. 1961. A review of the importance of fibre dimensions and fibre strength to pulp sheet properties. Ontario Research Foundation, Carbohydrate Research Report ORF-4 (unpublished report, on file).

TABLE 11 Fibre pulping parameters

Clone	Flexibility coefficient[a]	Felting index[b]	L/T ratio[c]	Runkel ratio[d]
DN1	0.7942	43.14	460	0.2359
DN2	0.7668	44.23	472	0.2445
DN3	0.8298	38.85	457	0.2051
DN5	0.7879	42.55	458	0.2357
DN6	0.8004	41.30	440	0.2296
DN7	0.7985	43.89	453	0.2429
DN9	0.7911	42.94	451	0.2408
DN10	0.8025	43.46	486	0.2227
DN11	0.7914	38.49	377	0.2580
DN13	0.7968	45.16	446	0.2543
DN14	0.8097	40.36	429	0.2326
DN15	0.8339	40.62	489	0.1991
DN16	0.8365	28.82	477	0.1947
DN17	0.7728	28.42	358-	0.2774*
DN18	0.8141	47.69*	513	0.2283
DN19	0.7993	36.23	369	0.2459
DN20	0.8244	46.16	524	0.2137
DN21	0.8060	41.61	462	0.2237
DN22	0.8430*	26.13	469	0.1829-
DN23	0.7487-	42.95	405	0.2824
DN24	0.8143	46.55	500	0.2288
DN25	0.8230	43.13	493	0.2124
DN26	0.8295	40.21	473	0.2048
DN28	0.8228	45.17	520	0.2110
DN30	0.7923	42.50	448	0.2394
DN32	0.8239	41.89	477	0.2130
DN33	0.8374	41.30	510	0.1934
I-45/51	0.8252	45.48	557*	0.1080
I-214	0.8386	35.95	444	0.1931
I-455	0.8380	33.34-	420	0.1893

[a]Lumen diameter/cell diameter
[b]Cell length/cell diameter
[c]Cell length/cell wall thickness
[d]Double cell wall thickness/lumen diameter

Tissue Composition (Table 12)

Six of the best clones selected on the basis of the foregoing data on yield and quality were analysed for tissue composition. Bole xylem data were weighted proportional to volume. The results showed that fibre wall occupied from 23.2% to 29.7% of bole xylem cross section area. Bark averages were lower, ranging from 9.8% (DN21) to 17.9% (DN28). The variation in the percentage of fibre wall was less in xylem than in bark, reflecting the more diverse morphology of bark tissue. There was no evidence of correlation between incidence of fibre wall in these two tissues. The percentage of xylem tissue volume composed of fibre cells (wall and void) was relatively high, ranging from 52.1% (DN25) to 65.2% (I-45/51). Marton and Agarwal (1965) quote a value of 53.3% for cottonwood. Since fibre wall material contributes the vast majority of pulp, parenchyma being lost as "fines" and vessels contributing a small and marginal-value fraction, this feature is of prime interest (Fig. 4).

TABLE 12 Average tissue composition of selected clones

Clone	Percent of cross section area		
	Bole xylem (weighted)		Bark (unweighted)
	Fibre wall	Fibre cell	Fibre wall
DN10	29.30	62.48	15.00
DN20	23.98	56.04	13.65
DN21	27.19	64.99	9.85-
DN25	23.23-	52.14-	14.29
DN28	28.61	63.90	17.86*
I-45/51	29.67*	65.15*	12.72

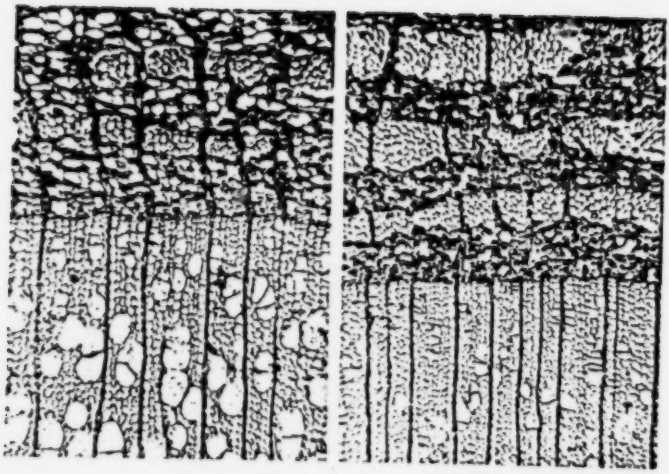

Figure 4 *Transverse sections (x75) of two clones exhibiting different physical and morphological properties. Left: second year xylem and bark of clone DN25 is relatively porous, with 23.2% of the xylem and 14.3% of the bark volume composed of fibre wall material. Right: similar tissue of clone DN10 appears more compact, with 29.3% of the xylem and 15.0% of the bark volume composed of fibre wall material. These differences are reflected in specific gravity data for clone DN25 (xylem 0.288, bark 0.254) and clone DN10 (xylem 0.327, bark 0.378).*

Within-tree Variation (Table 13)

An analysis of the influence of sampling position within a tree on intrinsic or unweighted values of fibre length, fibre wall thickness and specific gravity was accomplished for three trees of clone DN20, one of the most promising of the studied clones.

The fibre lengths were comparatively similar and tended to be short in tissues in their first relative year of development (in branch, second nodal increment, inner layer of first nodal increment). The tissues in their second relative year of development (in outer layer of first nodal increment), and especially the bark tissue, showed respectively longer fibre lengths. The longer fibres of the second (outer) layer as compared to the first(inner) layer within the first nodal increment was a consistent relationship for all 30 clones. The fibre wall thickness values for the bole wood tended to be similar, while the branchwood had thicker fibre walls, a reverse trend to that for fibre length. A similar relationship apparently exists in specific gravity values. These trends of fibre length, density and cell wall thickness with tissue age are in accord with the results of Smith and Rumma (1971).

TABLE 13 Average intrinsic fibre length, fibre wall thickness, and specific gravity values for various sampling positions within 2-year-old trees of clone DN20 (three trees pooled). Values shown are mean ± standard error of mean

Sample position	Fibre length (mm)	Fibre wall thickness (μm)	Specific gravity
Bolewood			
Two year-old bolt			
Inner layer	0.7268±0.0173	1.7229±0.0812	0.2816±0.0026
Outer layer	0.9139±0.0223	1.6542±0.0763	0.2777±0.0035
One year-old bolt	0.7415±0.0141	1.6667±0.0625	0.2910±0.0023
Branchwood	0.6992±0.0173	1.8188±0.0832	0.3036±0.0063
Bark	1.4201±0.0360		

Clonal Variation (Table 14)

Examination of the data for the six selected clones with replicate samples by means of analysis of variance suggests that, for both fibre length and specific gravity, variation among individuals within a clone was small enough to conclude that no real (significant) differences exist (error probability >5%). Variation between clones, however, was of greater magnitude and the analysis strongly suggests that real (significant) differences occur between the six separate clones (error probability <1%).

This "clonal variation" can perhaps be further appreciated when compared to the data of Boyce and Kaeiser (1961) who found that mean fibre length at breast height varied from 0.85 to 1.28 mm among 83 individuals of a wild population of cottonwood (*P. deltoides* Marsh).

Cech *et al* (1960) and Kennedy and Smith (1959) indicated that fibre length increased and density decreased with faster growth. The density correlation has also been demonstrated by Paul (1956). Such intraclonal relationships with growth rate were found to be inconsistent from clone to clone in our study, for either of the two year's growth under consideration.

The wide variation in many of the yield and wood characteristics indicates that a high selection potential exists among the studied clones. The relatively narrow within-clone range in studied traits suggest that levels of genetic control are strong enough to assure the effectiveness of clonal selection.

TABLE 14 Analysis of variance of mean tree fibre length and specific gravity values for clones DN10, DN20, DN21, DN25, DN28 and I-45/51

		Fibre length		Specific gravity	
Source of variation	Degrees of freedom	Sum of squares	F ratio	Sum of squares	F ratio
Clones	5	0.0627	6.09**	0.0034	3.7*
Trees within a clone	2	0.0070	1.70	0.0003	1.0
Error	10	0.0206		0.0019	
Total	17	0.0903		0.0056	

*significant at 5% level.
**significant at 1% level.

CLONAL SELECTION

The poplar clones used in fibre plantations have to be selected for many criteria. They have to root easily from stem cuttings and grow fast from the very start. They have to coppice vigorously; furthermore the stumps have to maintain the capacity for coppicing for the longest possible time, despite frequent harvesting of the sprouts. The selected clones must also have desired wood qualities and be resistant to diseases. Of the above criteria, the survival, coppice growth and the wood quality were studied. Dadswell and Wardrop (1959) and Dinwoodie (1965) suggest that desirable qualities for papermaking include (1) long fibres, (2) low basic density, (3) Runkel ratio of cell wall thickness less than unity and (4) high ratio of fibres to vessels and parenchyma. We will attempt to examine the relative performance of studied clones accordingly.

Ranking of clones in terms of studied parameters can be done in several ways. Obviously, many combinations of factors can be examined, and arguments concerning the relative degree and manner of importance of these are almost traditional. It should be remembered that a high rank does not necessarily imply an acceptable absolute value of the particular parameter.

Four different approaches were used: (1) Individual ranking on the basis of combined "yield" parameters of survival, green weight, specific gravity, percentage bark and percentage branches gave the highest composite score to clone DN10, followed by DN23 and DN28. Clones DN15, DN11 and I-455 ranked lowest in this series. Specific gravity was ranked, in this instance, as a positive attribute due to its direct correlation with bulk yield. Bark and branch biomass were taken to be negative in this rank. (2) A separate ranking was made which considered only branch and bark per cent (negative) and their appropriate fibre lengths (positive). With such procedure, clones DN26, DN20, and DN10 scored highest while DN14, DN13 and DN19 were of least value. While relative branch and bark contribution to yield has been negatively selected, the relative value of these tissues is increased when they are associated with longer fibres. (3) A consideration of wood quality was attempted using fibre length and wall thickness (positive) and specific gravity and tension wood content (negative). Such a composite score suggested that DN1, DN26, and DN25 were outstanding, and that DN9, DN23, and DN17 were poor performers. Higher density and tension wood may tend to lower pulp strength and therefore they were ranked negatively in regard to wood quality. (4) A ranking according to the sheet-forming performance of fibres (as estimated by L/T and Runkel ratios) indicated I-45/51 as best, followed by DN33 and DN28, while DN17, DN23 and DN11 ranked lowest.

Clones separated differently in value depending upon the criteria used to screen them. For example, I-45/51 scored "average" in yield but "superior" in paper value, while the reverse was true for clone DN23. Similarly, DN17 ranked first in cell wall thickness, bark and branch content and specific gravity, but last in fibre length. In a simplistic pooling of all the examined parameters, with specific gravity ranked in positive direction and tension wood, bark and branches as negative, the superiority of clones DN20, DN10, I-45/51, DN28, DN18 and DN25 is evident.

Such evaluations, however, are relevant to these clones only within the context of the "mini-rotation" and similar calculations for longer rotations or other uses could lead to different conclusions. Other factors such as rooting ability, stool longevity, disease resistance and ecological adapta-

bility are obviously of prime importance in clonal selection and would have to be considered in any final choice.

MANAGEMENT CONSIDERATIONS

Fibre production on densely grown, young coppices of poplar appears to be successful and reliable only with selected fast growing clones and on good sites. Furthermore, the plantation has to be in proximity of industries utilizing the fibre, and managed under conditions of intensive site preparation and culture. The advantages of such a system lie in the short investment periods, high yields, uniform raw material, maximum use of growing space, mechanization of planting, cultivation, harvesting and utilization, and reduced risks of long-term impact of diseases and insects.

The poplar clones used in fibre plantations have to be selected for many criteria. They must root easily from stem cuttings and show immediate fast growth. They have to coppice vigorously; furthermore the stumps must maintain the capacity for coppicing for the longest possible time, despite frequent harvesting of the sprouts. The selected clones must also have desired wood qualities and be resistant to diseases.

The site has to be prepared and maintained as for a farm crop. The stocking is dense. Unrooted stem cuttings, 20 cm in length, are excellent planting stock. The growth in the year of planting usually does not produce satisfactory fibre yields. In most cases only one sprout per root system develops and the height of the sprouts is between 0.5 and 2.0 m. Often it is profitable to cut these sprouts and use them as cuttings for planting stock. The root systems left in the ground will coppice vigorously the following year. Usually, 3 to 5 coppices per root system will develop, the average height of which will exceed 2 m. These can be harvested on an annual or bi-annual basis and used as fibre.

CONCLUSIONS

High yields of fibre of acceptable pulp and papermaking qualities can be produced in two-year rotations, with densely grown coppices of selected euramerican poplar clones.

The potential of clonal selection is high, and the juvenile, fast grown fibre of some clones shows properties similar to that of mature slower grown poplar.

Selected clones, good poplar sites, intensive management and close markets are the main prerequisites of a short rotation, poplar coppice culture program.

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